MIND WAVES
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ELECTRO MAGNETIC WAVES

INNOVATIVE STRATEGIES TO MASTER NCERT CONCEPTS WITH CRYSTAL CLARITY!

CONCEPT CLARITY + ESSAY- LEARNING

FOR OTHER UPDATES
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Electro Magnetic Waves.

The waves that are associated with electric and magnetic fields are called electro magnetic waves

principle of production Electro magnetic waves.

Electro magnetic waves are produced by changing

1) magnetic field produced by electric field.
2) electric field produced by magnetic field.

Conduction current (i_c):

The rate of flow of charge (or) as rate of change in magnetic field is called conduction current.

$$i_c = \frac{dq}{dt}$$

$$i_c \propto \frac{dB}{dt}$$

Displacement current

The rate of change in electric field is called Displacement current.

$$i_d \propto \frac{d\vec{E}}{dt}$$

The electric flux is given by $\phi = \vec{E} \cdot \vec{A}$

$$\phi = EA\cos\theta$$

where θ = angle btm field and coil.

Expression for Displacement current:

According to Gauss's law

$$\phi_E = \oint \vec{E} \cdot d\vec{A} = \frac{q}{\epsilon_0}$$

$$\phi_E = \frac{q}{\epsilon_0}$$

diff on b.s w.r.t t

$$\frac{d\phi_E}{dt} = \frac{1}{\epsilon_0} \cdot \frac{dq}{dt}$$

$$\frac{dq}{dt} = \epsilon_0 \frac{d\phi_E}{dt}$$

$$I_d = \epsilon_0 \frac{d\phi_E}{dt}$$

Between parallel plate capacitor

→ This current produced inside the conductor.

∴ The total current across the conductor is given by

$$I = I_c + I_d$$

$$\boxed{I = I_c + \epsilon_0 \frac{d\phi_E}{dt}}$$

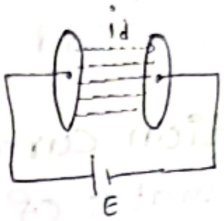
Note:

1) Inside the capacitor there is no conduction current ($i_c = 0$) and have only displacement current.

$$i = i_c + i_d$$

$$i = 0 + i_d$$

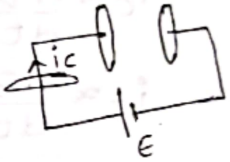
$$\boxed{i = i_d = \epsilon_0 \frac{d\phi_E}{dt}}$$



2) Outside the capacitor there is no displacement current ($i_d = 0$):

$$i = i_c + i_d$$

$$\boxed{i = i_c}$$



3) If the capacitor is charged then inside the capacitor both conduction and displacement current are produced.

$$\boxed{\therefore i = i_c + i_d}$$

Note:

Displacement current $i_d = \epsilon_0 \frac{d\phi}{dt}$.

$$C = \frac{\epsilon_0 A}{d} \Rightarrow \frac{A}{d} = \frac{C}{\epsilon_0}$$

$$E = \frac{V}{d}$$

$$\phi = E \cdot A$$

$$\phi = \frac{V}{d} \cdot A = \frac{VC}{\epsilon_0}$$

$$\epsilon_0 \phi = VC$$

$$\epsilon_0 \frac{d\phi}{dt} = C \cdot \frac{dV}{dt}$$

$$i_d = C \cdot \frac{dV}{dt}$$

$$\boxed{i_d = \frac{\epsilon_0 A}{d} \cdot \frac{dV}{dt}}$$

$$\boxed{i_d = \frac{\epsilon_0 \pi r^2}{d} \frac{dV}{dt}}$$

Maxwell's Equation.

. The total current passing through an area of closed loop produces magnetic field and is given by

$$\oint B \cdot dl = \mu_0 i$$

$$= \mu_0 [i_c + i_d]$$

$$= \mu_0 \left[i_c + \epsilon_0 \frac{d\phi}{dt} \right]$$

$$\boxed{\oint \vec{B} \cdot d\vec{l} = \mu_0 i_c + \mu_0 \epsilon_0 \frac{d\phi}{dt}}$$

Lorentz force:

A charge q is moving in an region containing electric and magnetic field with velocity 'v' then the net force acting on the charge is called lorentz force.

$$F_L = \vec{F}_e + \vec{F}_B$$

$$\boxed{F_L = q[\vec{E} + (\vec{v} \times \vec{B})]}$$

Guass's laws:

1) Guass's law in electricity

$$\oint \vec{E} \cdot d\vec{A} = \frac{q_{net}}{\epsilon_0}$$

2) Guass law in magnetism

$$\oint \vec{B} \cdot d\vec{A} = 0$$

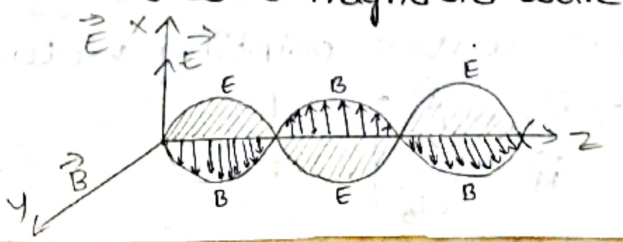
3) Faraday's law

$$\oint \vec{E} \cdot d\vec{l} = \frac{-d\phi}{dt}$$

4) Ampere Maxwell's law

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 i_c + \mu_0 \epsilon_0 \frac{d\phi}{dt}$$

Nature of Electro magnetic waves.



In electromagnetic waves, electric and magnetic waves perpendicular to each other and also perpendicular to the direction of propagation of the wave.

The instantaneous values of electric and magnetic fields are given by

$$\vec{E_x} = E_0 \sin(kz - \omega t)\hat{i}$$

$$\vec{B_y} = B_0 \sin(kz - \omega t)\hat{j}$$

where E_0, B_0 are amplitudes of the fields

$\omega = 2\pi f$ = Angular frequency.

$k = \frac{2\pi}{\lambda}$ = propagation constant.

The ratio of electric field component to the magnetic field component is called velocity of light.

$$c = \frac{E}{B} = \frac{E_0}{B_0} \text{ (medium)}$$

$$c_0 = \frac{E_0}{B_0} \text{ (Free space)}$$

velocity of light in Free space $c_0 = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$

velocity of light in medium $= \frac{1}{\sqrt{\mu\epsilon}} = c$

Refractive index.

$$\mu = \frac{c_0}{c}$$

$$\mu = \frac{\frac{1}{\sqrt{\mu_0 \epsilon_0}}}{\frac{1}{\sqrt{\mu\epsilon}}}$$

$$\mu = \sqrt{\left(\frac{\mu}{\mu_0}\right)\left(\frac{\epsilon}{\epsilon_0}\right)} \quad \left[\because \mu_r = \frac{\mu}{\mu_0}\right.$$

$$\mu = \sqrt{\mu_r \epsilon_r} \qquad \left.\epsilon_r = \frac{\epsilon}{\epsilon_0}\right]$$

Pointing vector ($\vec{P}$ (or) $\vec{S}$)

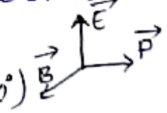
Pointing vector represents direction of energy flow. In case of electro magnetic waves, pointing vector is given by

$$\vec{P} = \vec{E} \times \vec{H} \quad \left[\because \vec{B} = \mu_0 \vec{H}\right.$$

$$\vec{P} = \frac{\vec{E} \times \vec{B}}{\mu_0} \quad \left.\vec{H} = \frac{\vec{B}}{\mu_0}\right]$$

$$P = \frac{1}{\mu_0} EB \sin\theta$$

$$P = \frac{EB}{\mu_0} \quad (\theta = 90^\circ)$$



Average energy density of em waves:

Average energy of static electric field

$$U_E = \frac{1}{2}\epsilon_0 E^2 \quad \left[\because U = \frac{1}{2}CV^2,\ C = \frac{\epsilon_0 A}{d},\ V = Ed,\ E = \frac{V}{d}\right]$$

Average energy of static magnetic field

$$U_B = \frac{1}{2}\frac{B^2}{\mu_0} \quad \text{---} (2)$$

If electric and magnetic fields varying sinusoidally w.r.t the time

$$U = U_E + U_B$$

$$U = \frac{1}{2}\epsilon_0 E_{rms}^2 + \frac{1}{2}\frac{B_{rms}^2}{\mu_0}$$

$\tan\phi = 1$ — LC circuit

But $E_{rms} = \frac{E_0}{\sqrt{2}}$ $\quad B_{rms} = \frac{B_0}{\sqrt{2}}$

$$U = \frac{1}{2}\epsilon_0 \frac{E_0^2}{2} + \frac{1}{2}\cdot\frac{\frac{B_0^2}{2}}{\mu_0}$$

$$U = \frac{1}{2}\epsilon_0 \frac{E_0^2}{2} + \frac{1}{2}\cdot\frac{B_0^2}{2\mu_0}$$

$$\boxed{U_{avg} = \frac{1}{4}\epsilon_0 E_0^2 + \frac{1}{4}\frac{B_0^2}{\mu_0}}$$

If average energy density of electric field is equal to average energy of magnetic field.

$$U_E = U_B$$

$$U = U_E + U_B \qquad \tan\phi = \frac{U_E}{U_B} = 1$$

$$U = 2U_E = 2U_B$$

$$U = \frac{1}{2}\left[\frac{1}{2}\epsilon_0 E_0^2\right] = \frac{1}{2}\left[\frac{1}{2}\frac{B_0^2}{\mu_0}\right]$$

$$\boxed{U = \frac{1}{2}\epsilon_0 E_0^2 = \frac{1}{2}\frac{B_0^2}{\mu_0}}$$

Intensity of em waves:

The intensity of electromagnetic waves is defined as the energy crosses the unit time per unit area of sure and ⊥lr to direction of propagation of the wave

$$I = \frac{U}{A \times t} = \frac{\frac{1}{2}\epsilon_0 E^2 (V)}{A \times t}$$

$$I = \frac{\frac{1}{2}\epsilon_0 E^2 (A \times d)}{A \cdot t} \quad [\because V = A \times d]$$

$$I = \frac{1}{2}\epsilon_0 E^2 c \quad \left[\because c = \frac{d}{t}\right]$$

$$I = \frac{1}{2}\epsilon_0 E_{rms}^2 c$$

In terms of magnetic field the intensity of em waves is

$$I = \frac{1}{2}\frac{B^2}{\mu_0} \cdot c$$

$$I = \frac{1}{2}\frac{B_{rms}^2}{\mu_0} \cdot c$$

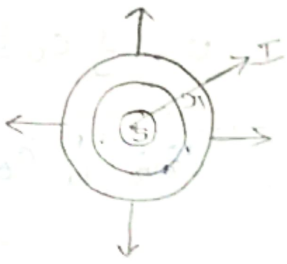
Note:

The radiation energy transmitted from an isotropic point source then the intensity at a distance 'r' is given by

$$I = \frac{P}{A}$$

$$I = \frac{P}{4\pi r^2}$$

P = power of source.



Momentum and Radiation pressure.

i) When an electro magnetic wave incident on a surface and its energy completely absorbed by the surface then the momentum delivered to the surface then.

$$E = mc^2$$

$$E = (mc)c$$

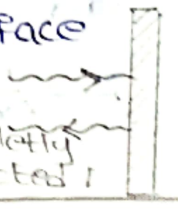
$$E = pc$$

$$p = \frac{E}{c}$$

$$p = \frac{U}{c} \quad [\because \text{complete absorption}]$$

ii) If energy completly reflected from the surface then the momentum delivered to the surface

$$p = \frac{2U}{c}$$



$$I = \frac{\frac{1}{2}\epsilon_0 E^2 (A \times d)}{A \cdot t} \quad [\because V = A \times d]$$

$$\boxed{I = \frac{1}{2}\epsilon_0 E^2 c} \quad \left[\because c = \frac{d}{t}\right]$$

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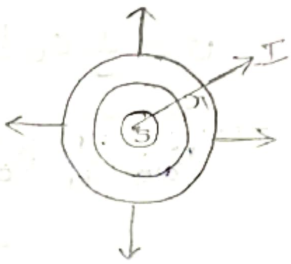

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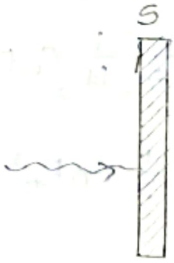

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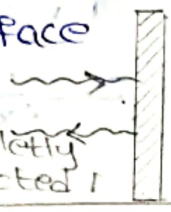

iii) If an electro magnetic wave is incident on a surface and absorbed by the surface completely then radiation pressure

$$I = \frac{U}{A \times t} = \frac{F \times S}{A \times t} \quad \left[\because P = \frac{F}{A}, \; c = \frac{S}{t}\right]$$

$$I = P_r c$$

$$\boxed{P_r = \frac{I}{c}}$$

c → velocity of light.

iv) If energy completely reflected from the surface then radiation pressure

$$\boxed{P_r = \frac{2I}{c}} \Rightarrow \text{completely reflected}$$

Wave Impedence (z):

$$z = \sqrt{\frac{\mu}{\epsilon}} = \sqrt{\frac{\mu_r}{\epsilon_r} \cdot \frac{\mu_0}{\epsilon_0}} \quad \left[\because \mu_r = \frac{\mu}{\mu_0}, \; \epsilon_r = \frac{\epsilon}{\epsilon_0}\right]$$

For vaccum:

$$\boxed{z = \sqrt{\frac{\mu_0}{\epsilon_0}} = 376.6\,\Omega}$$

For conducting medium:

$$\boxed{z = \frac{\mu\omega}{\sigma}}$$

$\because \mu$ = permeability of medium
ω = angular frequency.
σ = conductivity of the medium

EM wave spectrum.

The wavelength of electro magnetic waves arranged orderly to form electromagnetic spectrum.

γ-rays:

The wavelength of γ-rays is 10^{-14} to 10^{-10} m and its frequency 10^{20} Hz to 10^{18} Hz, these are produced by accelerated charges.

These are used in medical to detect cancer.

X-rays:

The wavelength of x-rays is 10^{-13} m to 10^{-9} m and its frequency 10^{21} Hz to 10^{17} Hz, these are produced by high energetic elections bombarded with target elements (W = tungsten)

These are used to detect fracture of bones.

U-V rays:

The wavelength of U-V rays is 10^{-11} m to 10^{-9} m and its frequency is 10^{15} Hz to 10^{18} Hz, these are used to find the structure of molecules.

Micro waves.

The frequency of micro waves is 1GHz to 30GHz. These are used in different fields.

Radio waves.

The frequency of radio waves is 1000MHz to 100 MHz. These are produced by acceleration of charges, theseee are used in T.V communication.